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Magnetic Linear Dichroism Probed by High Momentum Resolution EELS

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With the development of the spin-based electronics and nanoscale manipulation of structure, tremendous efforts have been focused on fabrication and characterization of nanomagnetic structures. Since the spin transport occurs through the bulk of multi-layered nanostructures, techniques, which are directly sensitive to the magnetic anisotropy within a bulk and its interfaces, are of great interest.

Previously, we attempted detection of nanometer scale magnetic anisotropy (magnetic linear dichroism (MLD)) in microcrystalline α-Fe_2O_3 (hematite) particles [1], using STEM-based momentum-resolved EELS [2]. α-Fe_2O_3 has antiferromagnetic ground state with spins on specific neighboring planes oriented in opposite directions. It exhibits magnetic phase transition at 263K (Morin temperature) due to the 90° flip of magnetic moments. MLD was manifested through a change of Fe L_{23} spectrum due to the change of the ratio of parallel to perpendicular components of the scattering vector (Fig. 1). However, further investigation showed inconsistent results due to the lack of angular resolution, specimen quality, and instrumental stability.

Here, we present more detailed and accurate study of the temperature and angular dependence of MLD on hematite with a superior angular resolution and consistency on a reliable single crystal α-Fe_2O_3 (hematite). We employed the high angular resolution electron channeling electron spectroscopy (HARECES) technique at 120kV with a FEI Tecnai F20 TEM/STEM. We have annealed the sample in air at 850°C in order to form stoichiometric hematite indicated by selected area diffraction spots due to the surface reconstruction [3].

Fig. 2 shows the calculated MLD spectrum based on the atomic multiplet calculation for the octahedrally coordinated Fe^{3+} ion in α-Fe_2O_3, showing distinct dependence of Fe L_{23} spectra on the orientation of the magnetic moments. Fig. 3 shows the corresponding experimental Fe L_{23} EEL spectra acquired above and below the Morin temperature with fixed acquisition geometry (2α = 0.15 mrad, 2β = 1.01 mrad). The incident beam was parallel to the c-axis of the (001) oriented single crystal specimen. The acquired Fe L_{23} spectra clearly exhibits changes due to the temperature change, and its trend agrees with the calculation in Fig. 2. The corresponding selected area diffraction patterns did not show the apparent change, indicating it was not structural origin. Most notably, spectra acquired in the HARECES mode provided us obvious differences in two L_2 spectra, which is comparable with MLD spectra by the synchrotron X-ray MLD experiment on a synthetic single crystal α-Fe_2O_3 [5] and the theoretical calculation in Fig. 2. Previous momentum resolved EELS experiments did not provide such a distinctive Fe L_2 spectra changes due to the lack of high quality signal [1,2,4]. Fig. 4 shows a comparison of temperature and angular dependence of Fe L_2 spectrum. The resemblance between the low temperature spectrum and the room temperature off-axis spectrum also supports that the spectrum features are magnetic origin. Finally, the present result convincingly supports that MLD obtained with HARECES is due to the magnetic anisotropy.

References

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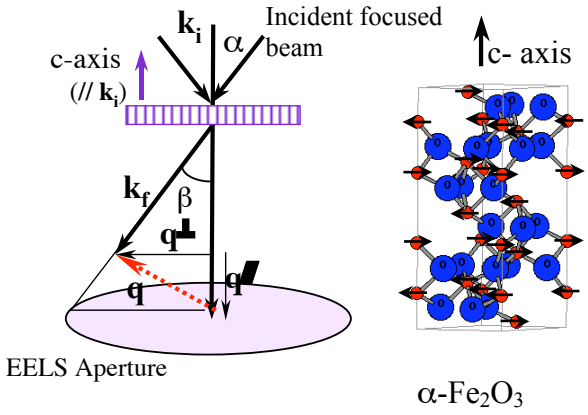

Fig. 1. Experimental geometry for MLD, and crystal and spin orientation of α-Fe_2O_3 at room temperature.

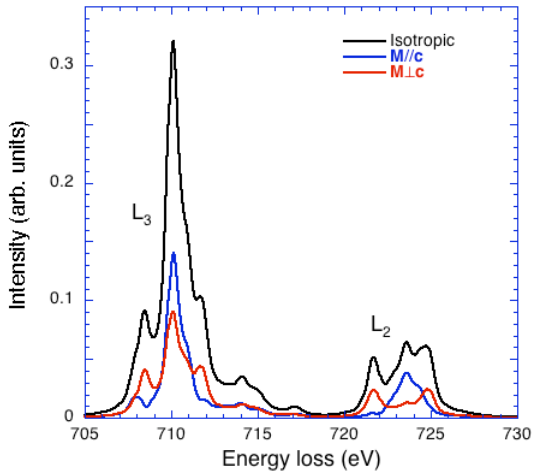

Fig. 2. Theoretical isotropic Fe^{3+} spectrum in α-Fe_2O_3 and its components. Spin orientation: Red: **M**$\perp$**c**; Blue: **M**//**c**; Black: Isotropic.

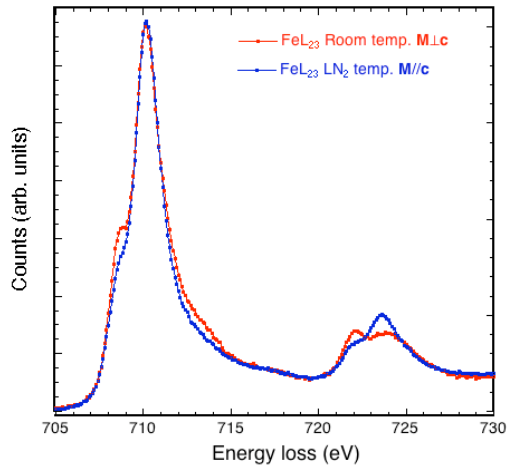

Fig. 3. Experimental Fe L_{23} of α-Fe_2O_3 (001). Red: room temperature; Blue: 95 K. 120 kV, 2α = 0.15 mrad, 2β = 1.01 mrad.

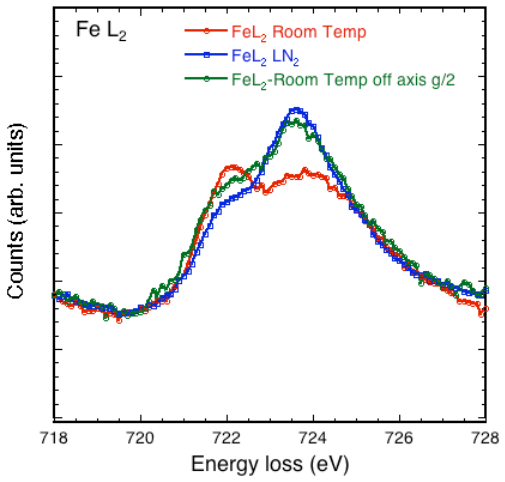

Fig. 4. Comparison of the enlarged Fe L_2 spectra of Fig. 3 and an off-axis Fe L_2 spectrum. Red: room temperature; Blue: 95 K; Green: g/2 off axis at room temperature.